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A Statistical Analysis of Loggerhead Turtle (*Caretta caretta*) Nesting Rates in Western Florida, 1997–2012

Confidential Final

Prepared for:

U.S. Fish and Wildlife Service
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1. Introduction

There is concern that the *Deepwater Horizon* oil spill that occurred between April and September of 2010 may have resulted in injuries to nesting success of loggerhead turtles (*Caretta caretta*). This species nests on beaches along the Gulf of Mexico, including many in Florida. National Oceanic and Atmospheric Administration reports (NOAA, 2013) summarizing observational data from the Shoreline Cleanup and Assessment Technique (SCAT) program, which were collected shortly after the spill, provide evidence of extensive shoreline oiling in the Panhandle region of the Florida coast. Cumulative composite maps of surface oil slicks indicate that surface oil was widespread in open-water areas south of the Florida Panhandle coastline (among other areas). Surface oil, shoreline oil, or both may have caused injuries to loggerheads through a variety of pathways and mechanisms.[1]

This report describes a statistical analysis of loggerhead nesting records designed to assess whether 2010 nesting rates on Florida Panhandle beaches were lower than would have been expected in the absence of the spill and, if so, to quantify the magnitude of the reduction.

Our approach to the task follows the Before-After Control-Impact (BACI) statistical modeling method described by Stewart-Oaten and Bence (2001). Briefly, our analysis addresses the hypothesis that loggerhead nesting in oiled areas of the Panhandle region of Florida may have been subjected to a negative impact of uncertain magnitude in 2010, while loggerhead nesting on the unoiled southwestern coast of Florida would not have been subject to such impacts. The BACI model assumes that (1) important general biological conditions that govern nesting rates in the two areas lead to a consistent statistical relationship in nesting rates in the two areas, and that (2) an impact that reduces nesting rates exclusively in the Panhandle region can be identified and quantified through the comparison of certain coefficients in an appropriate statistical model (described in Section 4).

2. Data Sources

A turtle nesting observation program conducted by the Florida Fish and Wildlife Conservation Commission (2012) has developed a long-term database of information about the amount of nesting activity at specific beaches, known as index beaches. Briefly, the program deploys trained observers annually to a fixed set of index beaches to count and record nesting activity daily from May 15 to August 31 (109 days). This observation program is designed to provide a complete census of nesting events at index beaches over the entire nesting season. The datasets

1. Detailed demonstrations of exposure pathways and mechanisms of injury are outside the scope of this report.

collected by the program have been used by Witherington et al. (2009) in a statistically based assessment of temporal trends in nesting rates in Florida. The temporal and geographic scope of their analysis, however, differs substantially from that considered in this report.

The index beaches considered in this report include three beaches in the southwestern portion of Florida's coast and three index beaches in the Florida Panhandle (Table 1, Figure 1). Nest counts are recorded according to subsections ("zones") that are partitions of each index beach.

The statistical analysis described in the following sections are based on data from the six index beaches cited in Table 1. Two additional index beaches in the panhandle region, Siesta Key and Egmont Key, have been part of the loggerhead nesting survey program since 1999. However, the datasets for those two beaches that are currently available to us are incomplete with respect to detailed information regarding dates and locations where counts were not conducted. Although the available datasets for Siesta Key and Egmont Key provide a reasonable approximation of total loggerhead nesting rates, they underestimate total nesting rates, and we could not conduct the imputation procedures (Section 3) required to quantify missing counts at those beaches. Consequently, we omitted those two beaches from our primary analysis. We conducted a brief supplemental analysis that included data from all eight index beaches to produce a rough indication of whether the conclusions derived from our analysis based on six index beaches would be substantially different if the inaccurate data from the additional beaches were included. The supplemental analysis indicated that key results regarding the magnitude of BACI impacts, including the two additional index beaches, were not substantially different (Section 5).

3. Data Aggregation and Imputation

Using the procedure of Witherington et al. (2009), we aggregated the nest counts that were initially recorded daily in each beach zone into annual beach totals before conducting regression modeling. The aggregation procedure converts daily zone level counts into total counts within eight biweekly periods.[2] In cases where daily counts were not recorded, counts for those days were assumed to equal the average number of nest counts observed in that zone on all other days within the same biweekly period.

A different imputation method is required in a case where data are completely absent for a particular zone and period. For the scope of data considered here, data were completely absent only for Period 8 of 2004 at Sanibel Island. We imputed the missing count data by assigning zone-level count values equal to the average zone-level counts recorded there from 2001 to 2003 and from 2006 to 2008. Although the data imputation method we employed for Period 8 of 2004 at Sanibel Island differs from the imputation method of Witherington et al. (2009), we believe

2. The first 98 days of the season are divided into seven 14-day periods, and the final period consists of 11 days.

that using a simpler imputation method is appropriate for our dataset because the typical nesting rates in Period 8 at Sanibel Island are near zero, and the practical effect of these data imputations on subsequent statistical analysis is negligible. Other minor data cleanup steps are described in Table A.1.

Annual total nest counts for an index beach were defined as the sum of all zone-level counts for all eight periods (Table 2, Figure 2).

4. Regression Analysis

Annual total nest counts per kilometer at six index beaches from 1997 to 2012 (Table 3) were the basis of regression modeling, where Santa Rosa Island, Panama City and St. Joseph Peninsula State Park (St. Joe PSP) were categorized as located in the Panhandle region and potentially subject to oil impact in 2010, while Sanibel Island, Wiggins Pass, and Keewaydin Island were categorized as located in the southwest coast region and not subject to oil impact. We used a linear mixed model (Equations 1–11) to estimate the degree to which observed 2010 nesting rates in the Florida Panhandle differed from the expected nesting rates.

$$\tau_{ijkl} = \mu_{ij} + \alpha_{ik} + \beta_{jl} + \alpha\beta_{ijkl} \tag{1}$$

$$\alpha_{ik} \sim N(0, \sigma^2_{beach}) \tag{2}$$

$$\beta_{jl} \sim N\left(0, \sigma^2_{year}\right) \tag{3}$$

$$\alpha\beta_{ijkl} \sim N(0, \sigma^2_{obs}) \tag{4}$$

$$\mathrm{E}\left(Y_{ijkl} \middle| \alpha_{ik}, \beta_{jl}, \alpha\beta_{ijkl}\right) = m_{ik} \times e^{\tau_{ijkl}} \tag{5}$$

$$\mathrm{Var}\left(Y_{ijkl} \middle| \alpha_{ik}, \beta_{jl}, \alpha\beta_{ijkl}\right) = \varphi \times m_{ik} \times e^{\tau_{ijkl}} \tag{6}$$

$$\mathrm{Cov}\left(Y_{ijkl}, Y_{ijkl'}, l - l'\right) = 1|\alpha_{ik}, \beta_{jl}, \alpha\beta_{ijkl} = \varphi_1 \times m_{ik} \times \sqrt{e^{\tau_{ijkl}} e^{\tau_{ijkl'}}} \tag{7}$$

$$\mathrm{Cov}\left(Y_{ijkl}, Y_{ijkl'}, l - l'\right) = 2|\alpha_{ik}, \beta_{jl}, \alpha\beta_{ijkl} = \varphi_2 \times m_{ik} \times \sqrt{e^{\tau_{ijkl}} e^{\tau_{ijkl'}}} \tag{8}$$

$$\mathrm{Cov}\left(Y_{ijkl}, Y_{ijkl'}, l - l'\right) = 3|\alpha_{ik}, \beta_{jl}, \alpha\beta_{ijkl} = \varphi_3 \times m_{ik} \times \sqrt{e^{\tau_{ijkl}} e^{\tau_{ijkl'}}} \tag{9}$$

$$\mathrm{Cov}\left(Y_{ijkl}, Y_{ijkl'}, l - l'\right) = 4|\alpha_{ik}, \beta_{jl}, \alpha\beta_{ijkl} = \varphi_4 \times m_{ik} \times \sqrt{e^{\tau_{ijkl}} e^{\tau_{ijkl'}}} \tag{10}$$

$$\mathrm{Cov}\left(Y_{ijkl}, Y_{ijkl'}, l - l' > 4|\alpha_{ik}, \beta_{jl}, \alpha\beta_{ijkl}\right) = 0 \tag{11}$$

Where:

i	=	type of beach, $i = 1, 2$
j	=	type of year, $j = 1, 2$
μ_{ij}	=	fixed effect mean (log scale) for beach type i in year type j
k	=	specific beach within a type of beach, $k = 1, 2, 3$
α_{ik}	=	random effect of beach k of type i
l	=	specific year within a type of year, $l = 1, \ldots, 15$ for non-impact years, $i = 1$ for 2010
β_{jl}	=	random effect of year l of year type j
$\alpha\beta_{ijkl}$	=	random effect of beach-year kl, of type ij, i.e., a single observation
φ_i	=	covariance of annual lag of i years where $i \in \{1,2,3,4\}$
m_{ik}	=	length of beach k of type i, in km
Y_{ijkl}	=	number of nests in beach k of type i in the year l of type j.

The model is specifically described as an over-dispersed quasi-Poisson model and the terms in the model can be categorized by how they contribute to the variance structure (Table 4). The model includes terms that reflect the fixed effect of the average nesting rates in the two coastal regions, random effects for year, beach and observation, and interaction terms. Coefficients were estimated using SAS Proc Glimmix, version 9.3.

The model also accounts for the possibility of temporal autocorrelation within beaches, which is plausible because individual loggerheads are thought to exhibit two- or three-year nesting cycles (Turtle Expert Working Group, 2009; Hays et al., 2010). The size and consistency of that periodicity are uncertain, so we have included autocorrelation terms that could capture cycles with periods ranging from one to four years in the model. Equation 7 represents the covariance between two observations on the same beach separated by one year. Similarly, Equations 8–10 represent the covariance for observations separated by two, three, or four years, respectively, and the covariance for autocorrelation with a lag of four or more years is defined to be zero (Equation 11).

5. Key Results for Index Beaches

The size and statistical significance of the interaction term for coast segment (Panhandle or southwest) and impact year (2010 or other) are the key indicators of how 2010 nesting rates observed in the Panhandle differ from the expected nesting rates (Table 5). The analysis indicates that the value of the interaction term is statistically different from zero ($p = 0.0173$), and that 2010 loggerhead nesting rates in the Panhandle were below the expected rates derived from the model. Table 6 describes the modeled contrasts for the key terms, and Table A.2 itemizes the covariance estimates derived from the model estimation. The contrast for the BACI-effect interaction term indicates that the 2010 estimated median nesting rate in the Panhandle was 56.3% (95% CI: 35–90%, $p = 0.0173$) of the expected rate, i.e., a reduction of 43.7% (95% CI: 10–65%, $p = 0.017$).[3] The modeling therefore provides evidence that some factor caused 2010 nesting rates in the Panhandle to be reduced, and that the magnitude of that reduction was greater than could be expected as a result of random variation from geographic and temporal factors.

The modeled nesting rates in both coastal regions are shown in Figure 3, where the red line segment indicates the modeled estimate for the 2010 nesting rate in the Panhandle region, if the (region * impact year) interaction were assumed to be zero, as would be expected if the trend in the Panhandle in 2010 were found to be identical to that in the southwest region. The modeled value with interaction assumed to be zero (the median), 1.519 nests/km, is an estimate of the Panhandle nesting rate that would have been realized in the absence of the BACI effect. Relating this estimate to the reduction rates described above, we could estimate the number of absent nests as 0.663 nests/km.

6. Conclusions

The results described in Section 5 quantify the reduction in Panhandle nesting rates that were estimated based on the conclusion that the 2010 "year effect" differed between the Panhandle and the southwest coast regions (i.e., non-zero interaction), and alternative estimates if year 2010 had been typical for both regions (i.e., zero interaction). The findings were determined through application of a linear-mixed regression model designed to reflect the geographic locations of index beaches and their vulnerability to potential injurious effects of the oil spill, using data from index beaches only.

Although the modeling was based on data collected at index beaches only, it is useful to express the findings in terms of a broader geographic scope and of "absent" nests, in addition to simply a reduction percentage. To do this, we assume that the factors affecting nesting rates among index beaches are practically the same as those affecting non-index beaches in the same region. We are unable to test that assumption with available data.

The three index beaches in the Panhandle region comprise 64.2 km of coastline, while there are 377.8 km of coastline suitable for nesting in the Panhandle region (Table 7). Considering the estimated value of a 0.663 nests/km reduction in nesting rate in the Panhandle region (Section 5), we calculate that approximately 251 nests would have been "absent" in that region in 2010.

3. The corresponding estimate from the analysis that includes data from two additional index beaches is a reduction of 39.6% (95% CI 2.5–62.6%, $p = 0.039$).

References

Florida Fish and Wildlife Conservation Commission. 2012. Fish and Wildlife Research Institute, Index Nesting Beach Survey Program Database. Data tables provided by Chip Wood, USFWS, April 9, 2013.

Hays, G.C., S. Fossette, K.A. Katselidis, G. Schofield, and M.B. Gravenor. 2010. Breeding periodicity for male sea turtles, operational sex ratios, and implications in the face of climate change. *Conservation Biology* 24(6):1636–1643.

NOAA. 2013. SCAT Data Series, Sector Mobile Maximum Oiling Extent as of 4/23/2011. Downloaded from NOAA/ERMA website: http://gomex.erma.noaa.gov/erma.html#x = -85.16682&y = 29.87627&z = 7&layers = 23385 + 16118. Accessed July 21, 2013.

Stewart-Oaten, A. and J.R. Bence. 2001. Temporal and spatial variation in environmental impact assessment. *Ecological Monographs* 71(2):305–339.

Turtle Expert Working Group. 2009. An Assessment of the Loggerhead Turtle Population in the Western North Atlantic Ocean. NOAA Technical Memorandum NMFS-SEFSC-575.

Witherington, B., P. Kublis, B. Brost, and A. Meylan. 2009. Decreasing annual nest counts in a globally important loggerhead sea turtle population. *Ecological Applications* 19(1):30–54.

Table 1. Attributes of index beaches

Coast segment	Index beach name	Beach code number	Number of zones	Average zone length (m)	Total length (m)
Southwest	Sanibel Island	b26	6	1,428	8,567
	Wiggins Pass	b27	8	983	7,864
	Keewaydin Island	b28	9	776	6,988
Panhandle	Santa Rosa Island	b29	27	777	20,990
	Panama City	b30	35	807	28,246
	St. Joe PSP	b31	36	417	15,000

Table 2. Annual total loggerhead nest counts by beach

	Southwest			Panhandle[a]		
Year	Sanibel Island	Wiggins Pass	Keewaydin Island	Santa Rosa Island	Panama City	St. Joe PSP
1989	16.0	76.0	90.0			
1990	14.0	161.8	137.2			
1991	30.0	138.0	188.0			
1992	26.0	186.3	100.0			
1993	28.0	143.1	119.0			
1994	35.0	146.0	160.0			
1995	39.0	212.1	142.5			
1996	56.0	190.0	117.0			
1997	35.0	151.0	132.0	17.3	31.0	122.8
1998	47.0	192.0	190.0	15.0	24.0	110.0
1999	41.0	195.0	137.0	17.0	24.2	194.2
2000	56.0	191.0	154.0	27.0	26.0	128.0
2001	29.0	144.0	143.0	12.0	13.2	118.0
2002	10.0	95.0	105.0	5.0	20.0	124.0
2003	30.0	180.0	184.0	15.0	10.0	70.0
2004	36.3	101.0	107.0	13.0	29.9	72.0
2005	13.0	87.0	87.0	3.2	22.3	106.2
2006	17.0	81.0	129.0	15.0	10.0	86.3
2007	35.0	72.0	90.0	4.1	13.0	82.2

Table 2. Annual total loggerhead nest counts by beach (cont.)

	Southwest			Panhandle[a]		
Year	Sanibel Island	Wiggins Pass	Keewaydin Island	Santa Rosa Island	Panama City	St. Joe PSP
2008	32.0	97.0	144.0	15.0	19.0	109.1
2009	25.0	81.0	112.0	14.0	16.0	71.1
2010	20.0	131.0	143.0	5.1	16.0	51.0
2011	34.0	106.0	159.2	16.0	16.1	82.8
2012	65.0	241.0	155.8	33.0	39.0	193.4

a. No nest count surveys were conducted in the Panhandle before 1997.

Table 3. Annual total loggerhead nest counts per kilometer by beach

	Southwest			Panhandle[a]		
Year	Sanibel Island	Wiggins Pass	Keewaydin Island	Santa Rosa Island	Panama City	St. Joe PSP
1989	1.868	9.664	12.879			
1990	1.634	20.579	19.627			
1991	3.502	17.548	26.903			
1992	3.035	23.691	14.310			
1993	3.268	18.192	17.029			
1994	4.085	18.566	22.896			
1995	4.552	26.968	20.397			
1996	6.536	24.161	16.743			
1997	4.085	19.202	18.890	0.826	1.097	8.189
1998	5.486	24.415	27.189	0.715	0.850	7.333
1999	4.786	24.797	19.605	0.810	0.856	12.945
2000	6.536	24.288	22.038	1.286	0.920	8.534
2001	3.385	18.311	20.464	0.572	0.466	7.867
2002	1.167	12.080	15.026	0.238	0.708	8.267
2003	3.502	22.889	26.331	0.715	0.354	4.667
2004	4.241	12.843	15.312	0.619	1.058	4.800
2005	1.517	11.063	12.450	0.155	0.789	7.081

Table 3. Annual total loggerhead nest counts per kilometer by beach (cont.)

	Southwest			Panhandle[a]		
Year	Sanibel Island	Wiggins Pass	Keewaydin Island	Santa Rosa Island	Panama City	St. Joe PSP
2006	1.984	10.300	18.460	0.715	0.354	5.752
2007	4.085	9.156	12.879	0.194	0.460	5.482
2008	3.735	12.335	20.607	0.715	0.673	7.272
2009	2.918	10.300	16.027	0.667	0.566	4.742
2010	2.334	16.658	20.464	0.242	0.566	3.400
2011	3.969	13.479	22.777	0.762	0.569	5.527
2012	7.587	30.646	22.300	1.572	1.381	12.896

a. No nest count surveys were conducted in the Panhandle before 1997.

Table 4. Terms included in the linear mixed model

Effect type	Effect term	Meaning
Fixed effects	Year type	An indicator term to estimate effects specifically associated with year 2010 (takes value 1 if year = 2010 or 0 otherwise)
	Coast segment (Panhandle or southwest)	A factor to distinguish beaches located in the Panhandle (impact area) from beaches located on the southwest coast (control area)
	Interaction: (year type * coast segment)	Estimates the degree to which effects associated with year 2010 differ between coast segments; the "BACI term"
Random effects	Year	Accounts for annual variation in nest counts among years
	Beach	Accounts for annual variation in nest counts among beaches
	Year * beach	Random effect of observations
Correlation	Covariance of 1-year lag	Accounts for correlation in nest counts within beaches observed one year apart
	Covariance of 2-year lag	Accounts for correlation in nest counts within beaches observed two years apart
	Covariance of 3-year lag	Accounts for correlation in nest counts within beaches observed three years apart
	Covariance of 4-year lag	Accounts for correlation in nest counts within beaches observed four years apart

Table 5. Type III tests of fixed effects

Effect	Degrees freedom (numerator)	Degrees freedom (denominator)	F value	Pr > F
Impact year	1	14	1.19	0.2928
Coast segment	1	4	5.56	0.0778
Interaction: impact year * coast segment	1	74	5.93	0.0173

Table 6. Modeled estimates of nesting rates (nests/km) by impact status and coastline segment, and estimated interaction indicating the magnitude of the "BACI effect" that quantifies the modeled deviation from expected nesting rates among Panhandle beaches in 2010

Category of estimated quantity	Estimate [log(nests/km)]	Estimated fractional nesting rate among Panhandle beaches relative to expected nesting rates [log(fraction)]	95% confidence interval	Standard error	Median fraction of expected nesting rate (nests/km)	95% confidence interval on median
Panhandle, any year except 2010	0.418	–	(-0.905, 1.741)	0.664	–	–
Panhandle, year 2010 effect	-0.195	–	(-1.661, 1.270)	0.736	–	–
Southwest coast, any year except 2010	2.346	–	(1.025, 3.668)	0.663	–	–
Southwest coast, year 2010 effect	2.307	–	(0.868, 3.746)	0.722	–	–
Interaction contrast ("BACI effect")	–	-0.574[a]	(-1.043, -0.104)	0.236	0.56	(0.35, 0.90)

a. p-value = 0.0173.

Table 7. Relative size of index beaches and all turtle nesting beaches

Region	Index beach	Index beach total length (km)	Adjacent beaches total length (km)	Total length (km)
Southwest	Sanibel Island	8.6	241.7	250.3
	Wiggins Pass	7.9	28.8	36.6
	Keewaydin Island	7.0	64.2	71.2
Region total		23.4	334.8	358.2
Panhandle	Santa Rosa Island	21.0	98.0	119.0
	Panama City	28.2	56.3	84.6
	St. Joe PSP	15.0	159.3	174.3
Region total		64.2	313.6	377.8
Grand total		87.7	648.4	736.0

Totals may not sum due to rounding.

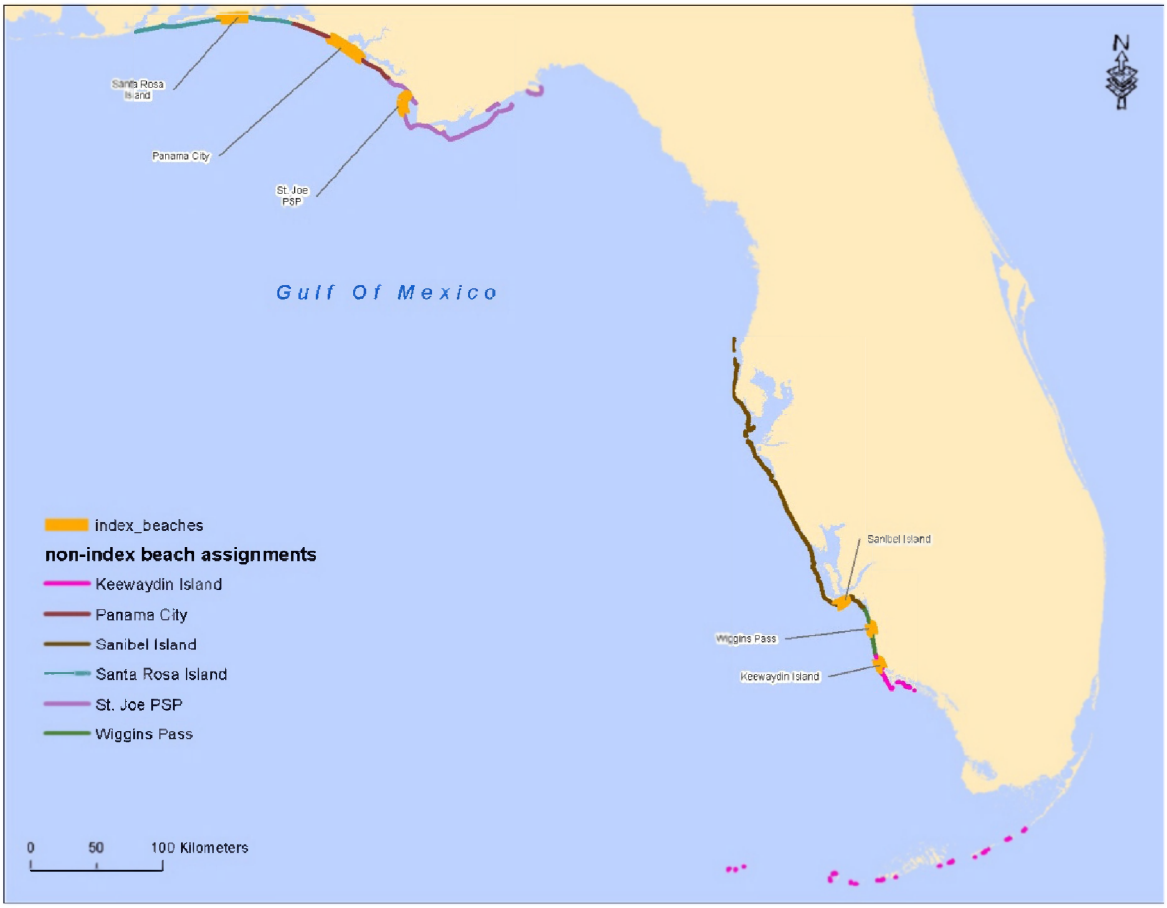

Figure 1. Map of loggerhead turtle nesting beaches in western Florida, including index beaches where systematic nest count data are collected and other non-index beaches.

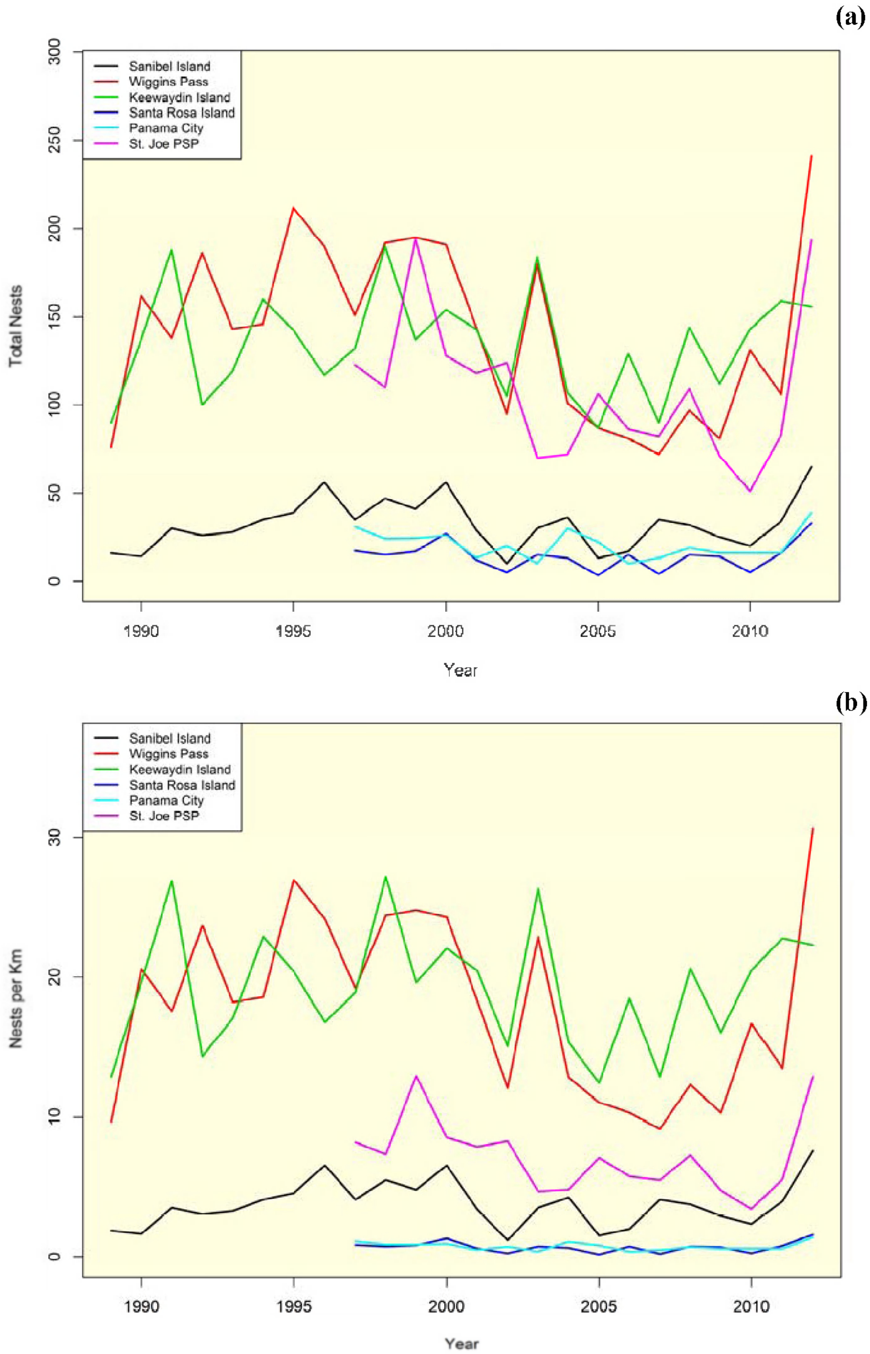

Figure 2. Empirical records of annual nesting rates counts at 6 index beaches; (a) total annual nest counts, (b) total annual nest counts per km.

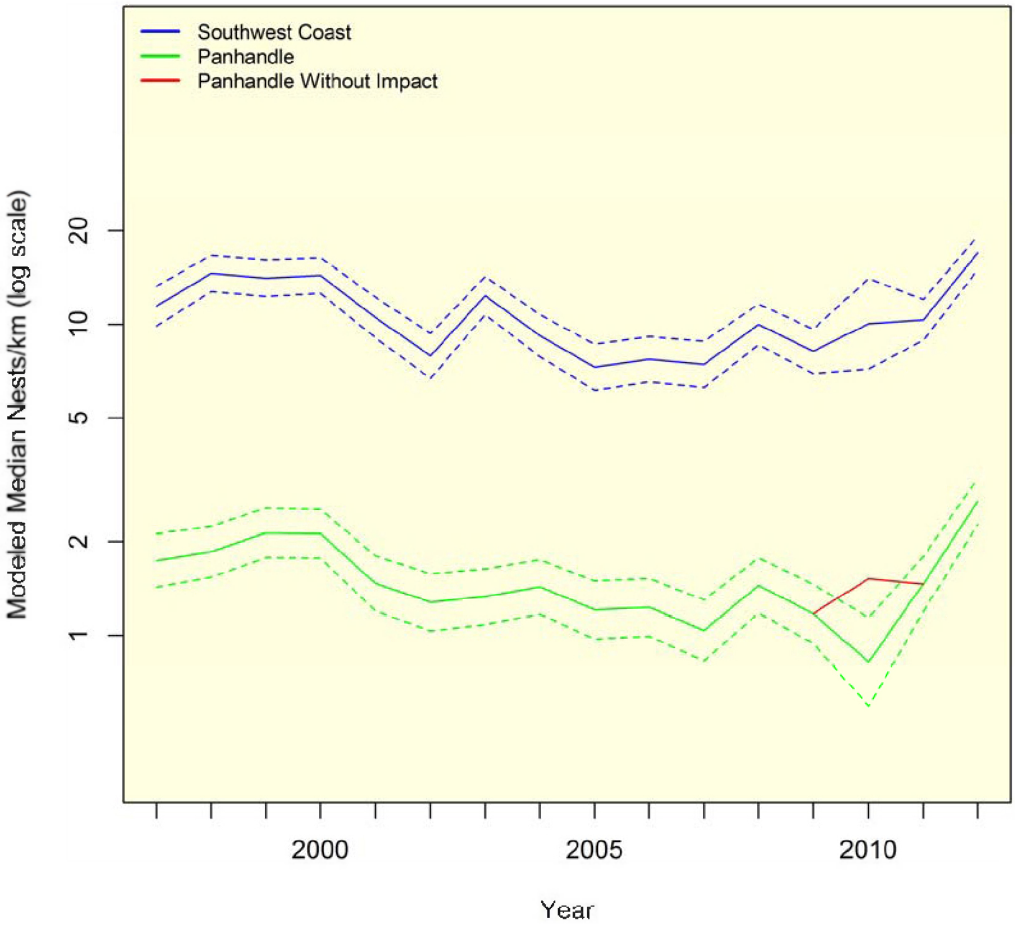

Figure 3. Modeled values of annual nesting rates (nests/km) in the southwest coast (blue lines) and the Panhandle (green lines) regions of Florida, and modeled estimate (red line) of the Panhandle nesting rate in the (hypothetical) absence of the 2010 year effect. Broken lines indicate the 95% confidence interval on the modeled median value.

Appendix

Table A.1 itemizes cases where preliminary data file editing was conducted prior to definitive analyses. The practical effects of these edits, individually or collectively, on the outcome of the analyses are believed to be negligible. Table A.2 itemizes estimated covariance values for the model described in Section 4.

Table A.1. Preliminary data treatments

Item	Action	Reason
1	Created a single aggregated nest count record for beach = 26, year = 2004, biweekly period = 8. Imputed nest count values for zones 1–6 were set to equal the mean counts observed at those locations in 2001–2003 and 2005–2007. Assigned values for zones 1–6 were 0, 0, 0, 0.1667, 0.1667, and 0, respectively.	No data records for beach = 26, year = \\sbofs\DWHScience\FWS.Turtle.Nesting\Reports\reportFinal20130930\PDF_SC13253_7.25.20132004, biweekly period = 8 are present in source data files.
2	Deleted one data record beach = 29, zone = 0, date = 7/6/2008, nest count value = 0.	Zone = 0 is an invalid entry.

Table A.2. Covariance parameter estimates

Parameter	Estimate	Standard error
Year within type	0.070	0.031
Beach within coast segment	1.302	0.926
Interaction: year * beach within (coast * type)	0.032	0.014
Covariance of 1-year lag	-0.354	0.548
Covariance of 2-year lag	-0.117	0.388
Covariance of 3-year lag	0.746	0.445
Covariance of 4-year lag	-0.315	0.480
Residual variance	1.718	0.782

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